

# Better-Than-Visual Technologies for Next Generation Air Transportation System Terminal Maneuvering Area Operations

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A consortium of industry, academia and government agencies are devising new concepts for future U.S. aviation operations under the Next Generation Air Transportation System (NextGen). Many key capabilities are being identified to enable NextGen, including the concept of Equivalent Visual Operations (EVO) – replicating the capacity and safety of today’s visual flight rules (VFR) in all-weather conditions. NASA is striving to develop the technologies and knowledge to enable EVO and to extend EVO towards a “Better-Than-Visual” (BTV) operational concept. The BTV operational concept uses an electronic means to provide sufficient visual references of the external world and other required flight references on flight deck displays that enable VFR-like operational tempos and maintain and improve the safety of VFR while using VFR-like procedures in all-weather conditions. NASA Langley Research Center (LaRC) research on technologies to enable the concept of BTV is described.

## Background

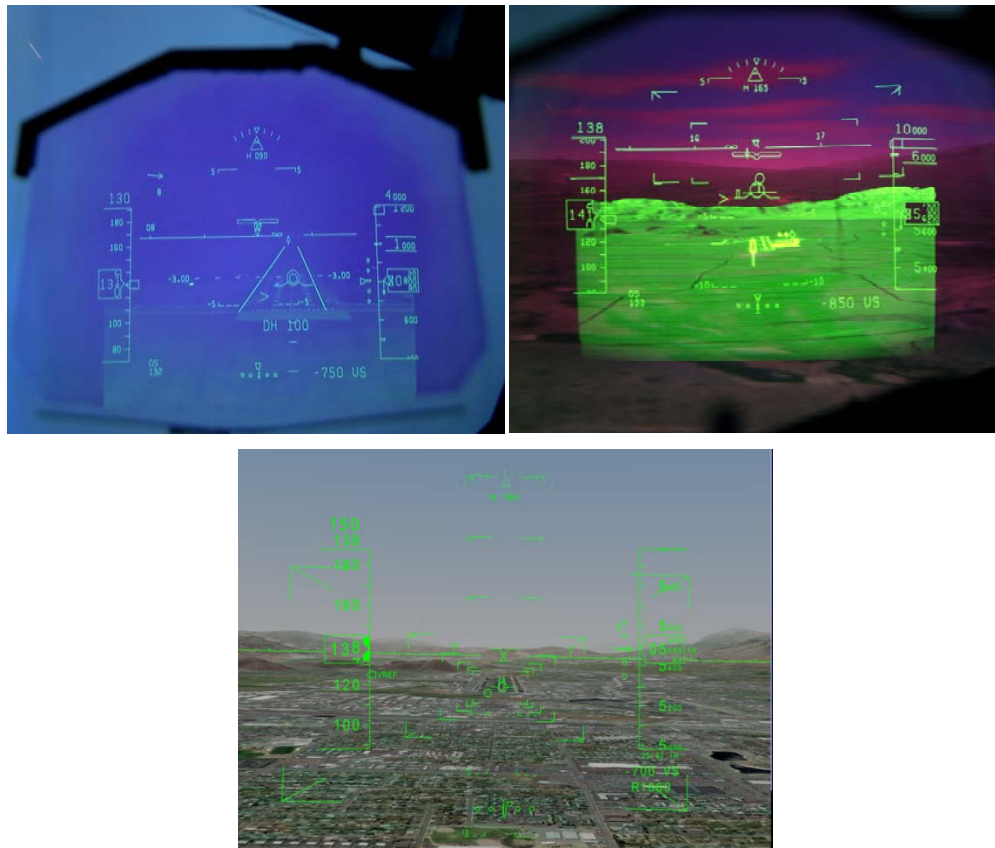
The Next Generation Air Transportation System (NextGen) concept for the year 2025 and beyond envisions the movement of large numbers of people and goods in a safe, efficient, and reliable manner. NextGen will remove many of the constraints in the current air transportation system, support a wider range of operations, and deliver significantly increased system capacity to that of current operating levels. New capabilities are envisioned for NextGen, including four-dimensional trajectory (4DT)-based operations, performance-based navigation, EVO, super density arrival/departure operations, network-centric operations, and digital data-link communication.

National Aeronautics and Space Administration (NASA) research, development, test, and evaluation (RDT&E) of flight deck interface technologies is being conducted to proactively overcome aircraft safety barriers that might otherwise constrain the full realization of NextGen. As part of this work, specific research issues associated with the NextGen Terminal Maneuvering Area (TMA) are being addressed: 1) the impact of emerging NextGen operational concepts, such as equivalent visual operations (EVO) and 4DT operations; 2) the effect of changing communication modalities within a net-centric environment; and, 3) the influences from increased pilot responsibility for self-separation and performance compliance. A high-level description of NASA Langley Research Center flight deck interface technology and research issues for these areas are described with references for further reading.

## Synthetic and Enhanced Vision Systems

Synthetic and Enhanced Vision System (SEVS) technologies are emerging as standard equipment on today’s flight deck. These technologies form the backbone of a BTV operational concept (Bailey, Prinzel, Kramer, and Young, 2011). SEVS generates intuitive visual references for the flight crew/pilot to fly the aircraft as if in visual flight conditions independent of the actual visibility or lighting conditions (see Figure 1). NASA LaRC research aims to extend the present-day SEVS concepts to enable VFR-like operational tempos and maintain and improve the safety of VFR while using VFR-like procedures in all-weather conditions. To meet this potential, research is focused on SEVS technology development and human-in-the-loop performance to enable a ‘visual’ approach, landing, roll-out, and surface operations down to 300 ft actual Runway Visibility Range. This BTV operational concept suggests that the minimum aviation system performance standard for BTV technologies should be that as defined by human performance in the same operation using windows during today’s VFR operations. Significant research is required to quantify this hypothesized performance standard, and more importantly, to determine if it is indeed an appropriate and sufficient standard for BTV. SEVS work includes the development of fusion methods for synthetic and

enhanced vision systems; feature extraction by use of real-time imaging sensors; on-board navigational, sensor, and database integrity monitoring; and appropriate display methods for Head-Up Displays (HUD) and Head-Worn Displays (HWD), primary flight and navigation displays, and electronic flight bags.



**Figure 1. Enhanced Vision HUD (Upper Left), Synthetic Vision HUD (Upper Right), Synthetic Primary Flight Display**

## Flight Deck Interval Management

Flight Deck Interval Management (FIM) leverages advancements in communications, surveillance, and navigation (CNS) to enable flight crews to precisely space their aircraft relative to another aircraft in the terminal maneuvering area. The goal is to improve airport throughput and reduce delays. Under FIM, the air traffic controller instructs the participating aircraft to achieve an assigned inter-arrival spacing interval at the runway threshold, relative to another aircraft, using on-board automation. The flight crew then takes responsibility to actively fly the FIM operation but the Air Navigation Services Provider (ANSP) retains the responsibility for aircraft separation. NASA LaRC research has demonstrated the efficacy of the concept and system-wide and algorithm effects (Barmore, 2009). Research has recently been completed showing the synergistic potential of combining FIM and SEVS technologies (Figure 2), broaching the concept of BTV. Simulation testing showed the ability of flight crews to self-separate, wherein the pilot/flight crew accepted responsibility for separation from the designated ‘paired’ aircraft, and maintained an “equivalent visual contact” through the use of ADS-B In and SEVS technologies (Figure 3). Spacing intervals during self-separation approaches followed VFR-like operational profiles while maintaining a very high degree of flight precision, stabilized approach procedures, and excellent traffic/situation awareness. Further, ego- and exo-centric display concepts for terrain, traffic, and airport surface conditions kept the flight crew ‘ahead’ of the operation and allowed them to easily manage the arrival, through landing, roll-out, and turn-off with acceptable workload and sufficient spare attention/workload capacity to easily react to non-normal events that were intentionally staged in the experiment.



Figure 2. Flight Deck Interval Management Primary Flight (left) and Navigation Display (right)

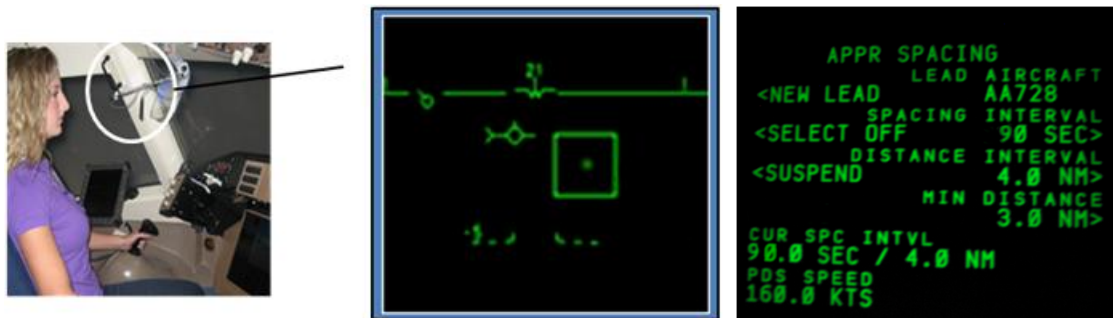


Figure 3. HUD Forward-Looking Infrared of Paired Traffic and Flight Management Computer Page

## Performance-Based Navigation

Performance-Based Navigation (PBN) is the umbrella term for navigation procedures being proposed to support NextGen operations which will enable aircraft to fly precisely desired flight paths leading to reduced delays, emissions, noise, and fuel costs. NASA LaRC flight deck display research has focused on the intuitive display of 4D trajectory-based operations through the use of synthetic vision pathway displays (Kramer et al, 2004; Prinzel et al, 2004) and flight path guidance and symbology (Kramer et al, 2003). This work also includes advanced decision support tools, notably Mission Rehearsal Tools (Figure 4; Arthur et al, 2006), which allow the pilot/flight crew to visualize the operation, preview procedures, and more importantly, preview the ANSP-proposed operation, the weather, and traffic using a user-friendly interface to evaluate and assess the proposed procedure before acceptance, or perform ‘what-if’ analyses of the proposed or alternate plans.

## Surface Flight Deck Displays

Previous research from Taxiway Navigation and Situation Awareness (T-NASA) research has shown that the key to preventing surface traffic conflicts is to ensure that pilots know: (a) where they are located, (b) where other traffic is located, and (c) where to go on the airport surface (e.g., see Foyle et al, 1996; McCann et al, 1998). The use of the HUD was central to this work to promote ‘eyes-out’ operations, ensuring that the pilot in control used the available visual cues for tactical path control and traffic/airport awareness, augmented by conformal HUD symbology. Recent research suggests that the use of HWDs which provide unlimited field-of-regard and integrated synthetic and enhanced vision with HUD-like symbology might offer additional benefits (Figure 5; Arthur, Prinzel, et al., 2006). Research is being conducted to address the operational confounds of symbology or imagery occlusion and/or attention capture when using a HWD during this ‘augmented reality’ environment.



**Figure 4. Electronic Flight Bag On-Board Graphical PBN Planning Tools**

The surface flight deck displays are not limited to head-up and head-mounted displays but extend to flight deck (cockpit) displays of traffic information (CDTI) for surface operations (Figures 6). Research has demonstrated that surface map displays can significantly enhance situation awareness and NASA LaRC concepts have focused on intuitive graphical display, including traffic, ownship path, other traffic status and intent, and airport status information emerging from Flight Information Services-Broadcast capabilities. This work becomes critically important as emerging NextGen concepts consider trajectory-based operations on the surface, such as 4DT surface guidance (see Cheng et al, 2004; Rathinam, Montoya, and Jung, 2008). The explicit display of intent information for surface routing was found to significantly enhance pilot awareness – critical when considering that intersecting taxiways and runways create potential collision opportunities and in limited visibility conditions, the flight crew may not be aware of which aircraft is first through an intersection or what their planned routing involves. Other innovations include decision support and interface tools to improve surface operations, such as text-to-speech and speech-to-text data-link interfaces and graphical display of turn-by-turn progressive taxi instructions, take-off and roll-out guidance, and runway exit turn-off braking guidance.



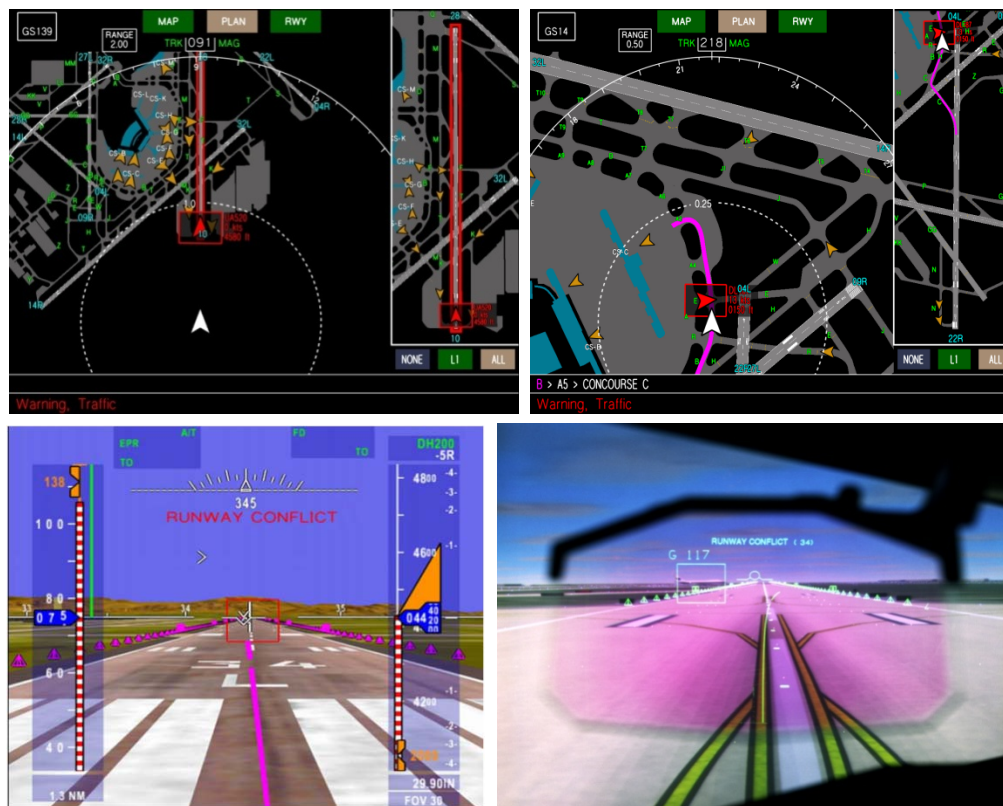
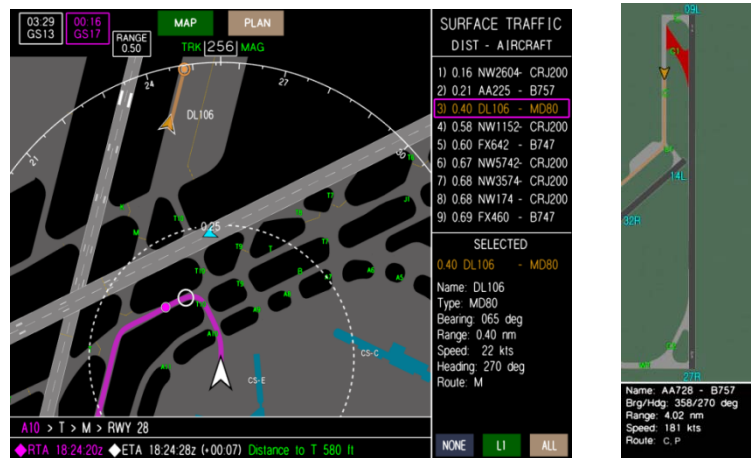
**Figure 5. Surface HUD / HWD Displays**

## Conflict Detection and Alerting

Research to develop data and design guidelines is actively being conducted to enable a comprehensive layer of indications, cautions, and warnings for safe TMA operations (Figure 7). This work initially started with runway incursion prevention where T-NASA surface display concepts were enhanced with active monitoring including predictive runway collision alerting and, if necessary, audible and visual alerting for deviations from the assigned taxi route and unauthorized crossing of a hold line (e.g., Jones et al, 2001). This work has been expanded for tactical and strategic surface operations awareness and Conflict Detection and Resolution (CD&R) functionality for NextGen operations, including taxiway and 4DT surface operational concepts (Green 2006, Jones 2002 and 2005, Jones, et. al., 2001, Jones and Prinzel, 2006; 2011; Jones, Prinzel, et al., 2010). This work includes the criticality of surveillance performance and operational scenario interactions emerging in NextGen. Monte Carlo and human-in-the-loop testing are being



conducted in a complementary fashion to identify the desired/required operational CD&R functionality, including definitions of acceptable missed detection and nuisance alerting for NextGen.



## Data Communications

By 2030 85% of Air Traffic Services communications are projected to be provided via data-link in the Airport/TMA environments (Eurocontrol, 2005). Net-centric operations hope to capitalize on a data-link environment's strengths. However, previous research has demonstrated numerous flight deck problems, including increased head-down time and pilot workload which, in a NextGen environment with closer

spacing and more pilot responsibility for 4DT separation, could significantly reduce safety margins. Furthermore, there are concerns of loss of “party-line” with data-link. NASA LaRC research has focused on the issues of data communications and prescriptions to enable NextGen operations (Figure 8; Prinzel, Shelton, et al., 2010). Research is being conducted to essentially identify (and retain) the best features of the present-day radio-based ‘party-line’ environment, while identifying and introducing the best features of a future data-link communications environment to assist in building NextGen.



**Figure 8. Data Communication Display Examples**

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